



Plans and study of JAXA's next SLR station

Takehiro Matsumoto
Japan Aerospace Exploration Agency

**Hiroyuki Ito, Katsuhide Yonekura,
Moeko Ryoki, Shin Miyatani,
Kyohei Akiyama, Sachiyo Kasho,
Takushi Sakamoto, Yuki Akiyama
and Shinichi Nakamura**
Japan Aerospace Exploration Agency

Hiroo Kunimori
National Institutes of Information and Communication Technology

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Backgrounds

▶ Deterioration of Tanegashima Station

- ✓ Tanegashima station(GMSL), located in the southwest of Japan, was established in 2004.
- ✓ It would be difficult to continue running for a long time since it is getting older.

▶ Our plans are:

- ✓ To establish a new SLR station.
- ✓ To introduce new SLR technologies such as kHz repetition rate, Infrared wavelength, SPAD and Optical fiber transmitter.
- ✓ To develop an inexpensive safety system using both ADS-B and infrared camera to replace radar system as used in Tanegashima station.



Demonstration Tests

► The purpose of demonstration tests

- ✓ We have conducted several demonstration tests to decide system requirements specification.

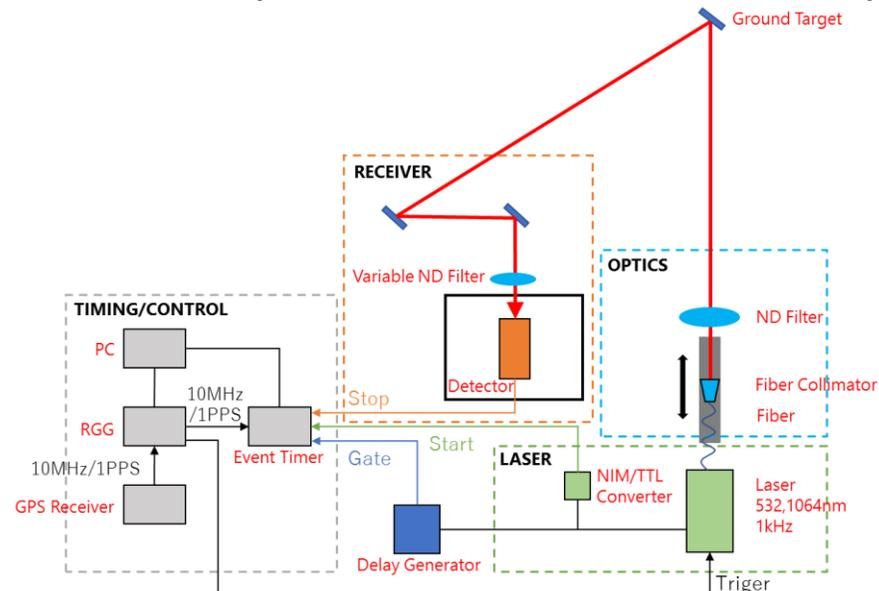
| Test | Purpose |
|----------------------|---|
| Prototype SLR Test | To investigate the availability of new SLR technologies |
| ADS-B Test | To examine whether they suit as a safety system |
| Infrared camera Test | |



Demonstration Tests - Prototype SLR Test -

► Prototype SLR Test

- ✓ This prototype was only for a ground target.
- ✓ We used both 532 nm and 1064 nm wavelength lasers whose pulse width was 1 ns and the repetition rate was 1kHz.
- ✓ SPAD with 50ps(FWHM) timing resolution was used as a detector for 532nm and APD with linear mode was used for 1064nm.
- ✓ To guide the laser pulse to the transmitter, we used multi-mode optical fiber instead of the Coude path.



| Laser | | |
|----------------------|--------------------|--------|
| Wavelength | 532nm | 1064nm |
| Pulse Width | 1ns | |
| Repetition Rate | ~1kHz | |
| Pulse Energy | >70μJ | >160μJ |
| SPAD (for 532nm) | | |
| Timing Resolution | < 50ps(FWHM) | |
| Dark Counts | < 100c/s | |
| Active Area Diameter | 100μm | |
| APD (for 1064nm) | | |
| Rise Time | 0.9ns | |
| Active Area Diameter | 1mm | |
| Optical Fiber | | |
| Core Diameter | 300μm (multi-mode) | |

Demonstration Tests - Prototype SLR Test -

► Results

- ✓ We succeeded in performing laser ranging to the ground target but there are still some problems.

| Technology | Result | Remark |
|---------------------------------|-----------|---|
| kHz Repetition Rate | Very good | - |
| SPAD | Good | Accuracy was limited (See Fig.1). Probably it was because of a wider pulse width of laser we used. |
| 1064nm wavelength | Good | Accuracy was limited. Probably it was because pulse width of our laser was wider and APD was linear mode. |
| Optical fiber-based transmitter | Fair | There was no problem in prototype SLR. However it has been reported that the main challenge when using a fiber in a SLR transmitter is avoiding fiber damage. |

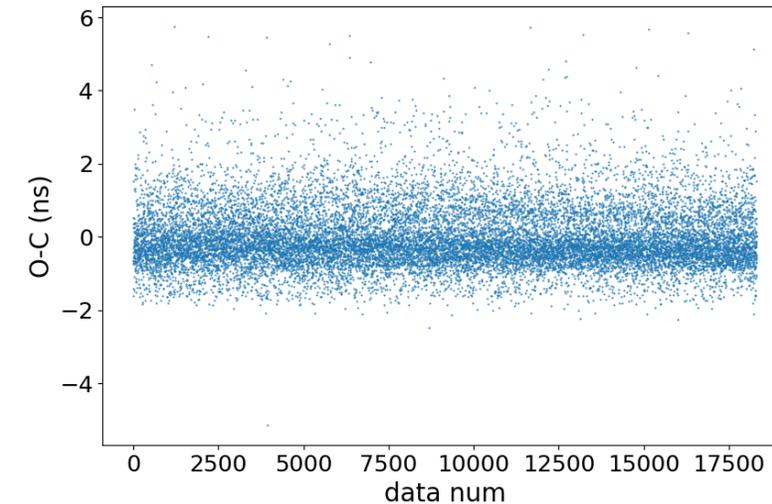


Fig.1 O-C plots

Wavelength : 532nm

Detector : SPAD

RMS : 677ps

Demonstration Tests - Safety System -

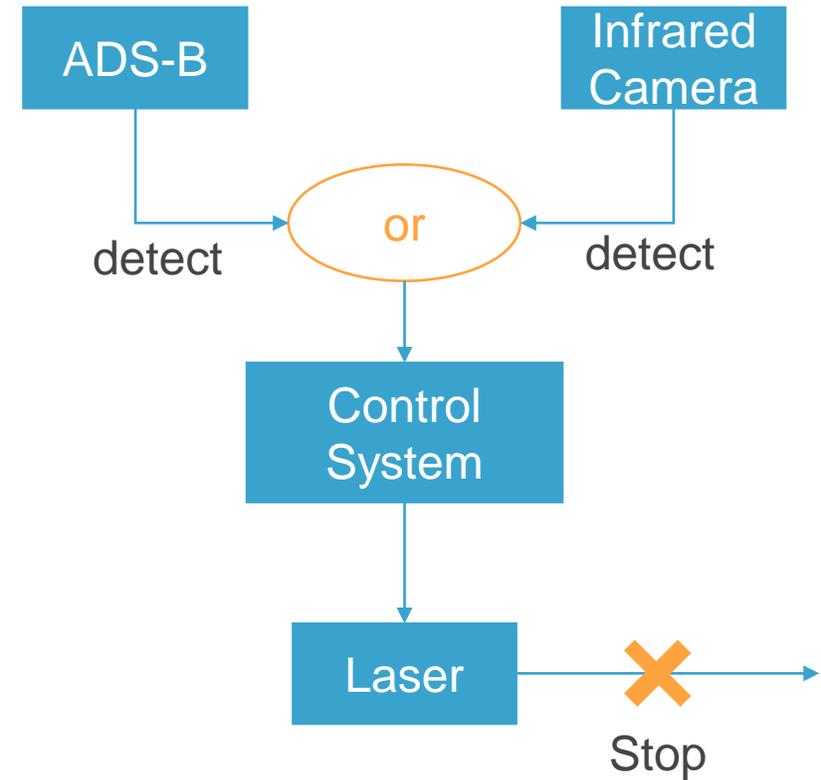
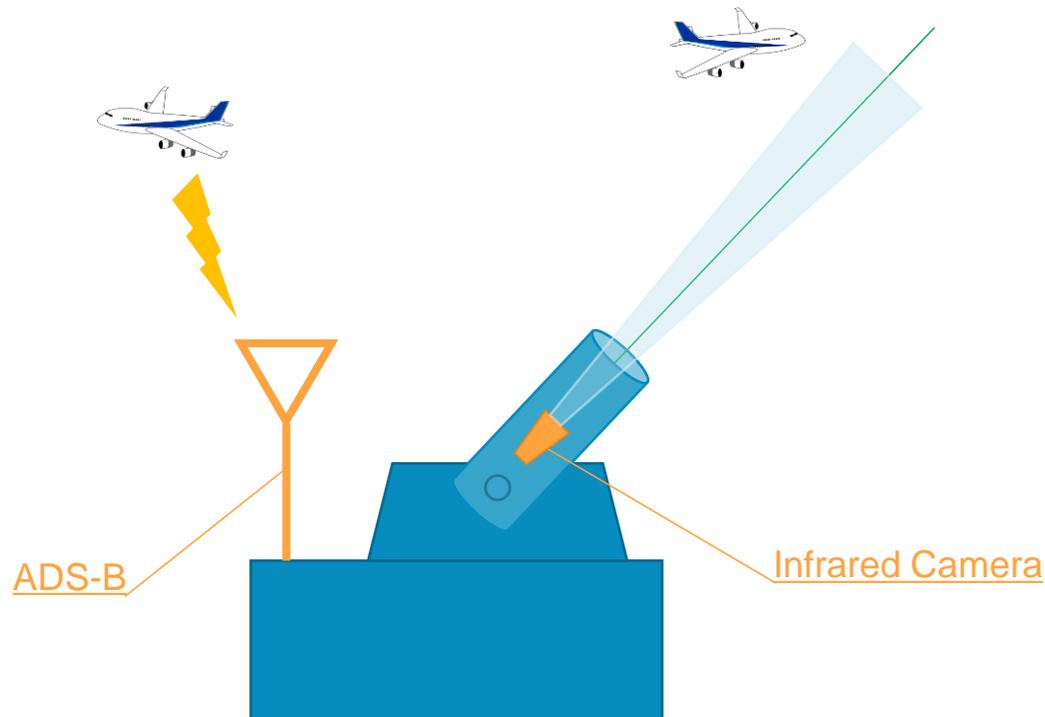
► Two sensors for safety system

✓ ADS-B

An aircraft which operates ADS-B broadcasts its latitude, longitude and altitude.

✓ Infrared Camera

An infrared camera monitors wider field of view than laser divergence angle.



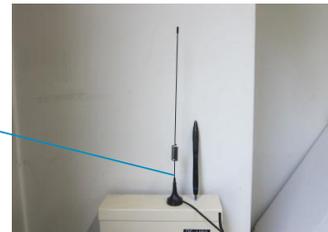
► Automatic System

Laser shot stops automatically when at least one of the two sensors detects an aircraft.

Demonstration Tests - ADS-B Test -

► Demonstration test for ADS-B

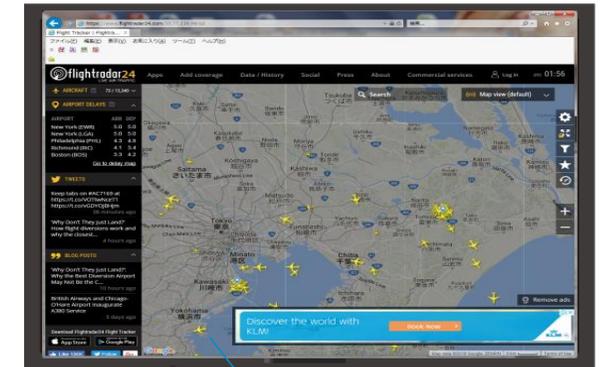
- ✓ Computer
 - Raspberry Pi 3 model B
- ✓ Receiver
 - RTL-SDR
- ✓ Software
 - Flight Rader24



Inexpensive antenna

► Results

- ✓ We succeeded in obtaining messages from aircrafts, their latitude, longitude and altitude.
- ✓ However **not all aircrafts operate ADS-B in Japan** and it is said that the accuracy of altitude included in the messages is not so good.



Flight Rader24



RTL-SDR

Raspberry Pi 3 model B

Demonstration Tests - Infrared camera Test -

► Demonstration test for Infrared Camera

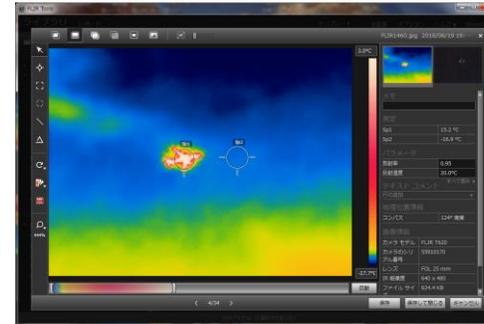
- ✓ Can an infrared camera distinguish an aircraft from the background?

| Camera | CPA E85S(FLIR) |
|-------------------|------------------|
| IR Resolution | 384 × 288 pixels |
| FOV | 24° × 18° |
| Temperature Range | -20~1200°C |

► Results

- ✓ We succeeded in clearly identifying the temperature (even the shape in the typical case) of an aircraft.
- ✓ We have to conduct additional test in the worst case(an aircraft is farther away) to examine this technology suits as a safety system.

Typical case

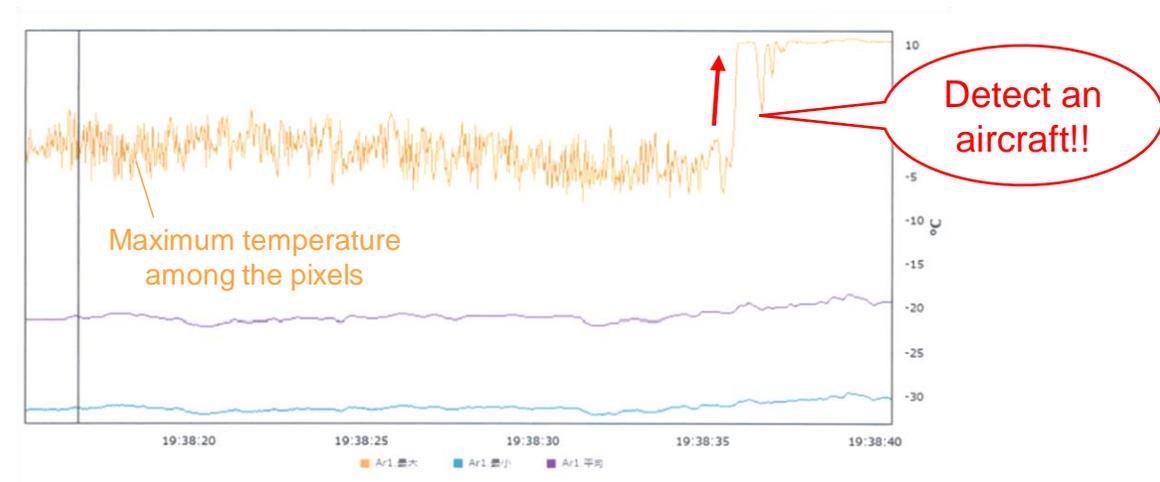


Elevation : 60°
Aircraft : 15°C
Background : -16°C
Difference : 31°C

Worse case



Elevation : 20°
Aircraft : -11°C
Background : -29°C
Difference : 18°C



Plans of next SLR station - Requirements -

► Main new features of next SLR station

| | Tanegashima | Next SLR |
|------------------|-------------|------------------------------|
| Wavelength | 532nm | 532nm and 1064nm |
| Repetition Rate | 10Hz | >1kHz |
| Receive Detector | MCP-PMT | SPAD or MCP-PMT |
| Transmitter | Coude path | Optical Fiber (under review) |
| Safety System | Radar | ADS-B and Infrared camera |

- ✓ 1064nm wavelength laser for uncooperative targets like space debris (It is just an experiment).
- ✓ Single-photon ranging with kHz repetition rate and SPAD or MCP-PMT.
- ✓ Optical fiber-based transmitter system is planned to mount. However this plan is now under review since it is not clear whether it can be realized. So they are not included in the minimum requirements of next SLR.
- ✓ ADS-B and Infrared camera are planned to used as a safety system.

Plans of next SLR station - Requirements -

▶ Concept

- ✓ Simple, compact and cost effective.

▶ Accuracy

- ✓ Single-Shot (RMS) < 20mm for LAGEOS
< 100mm for GEO
- ✓ Bias Stability (1σ) < 20mm

▶ Ranging Coverage

- ✓ Possible to track satellites from LEO to GEO.

▶ Remote Operation

- ✓ All system can be controlled from the remote site.
- ✓ The laser is automatically stopped if the safety system detects an aircraft.

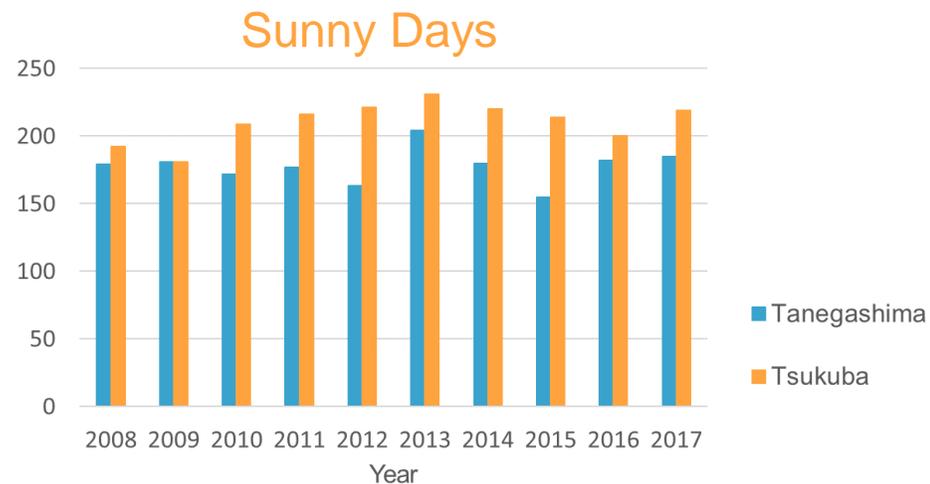
Plans of next SLR station - Location -

► Location

✓ Next SLR station will be located in Tsukuba Space Center, Ibaraki Prefecture.

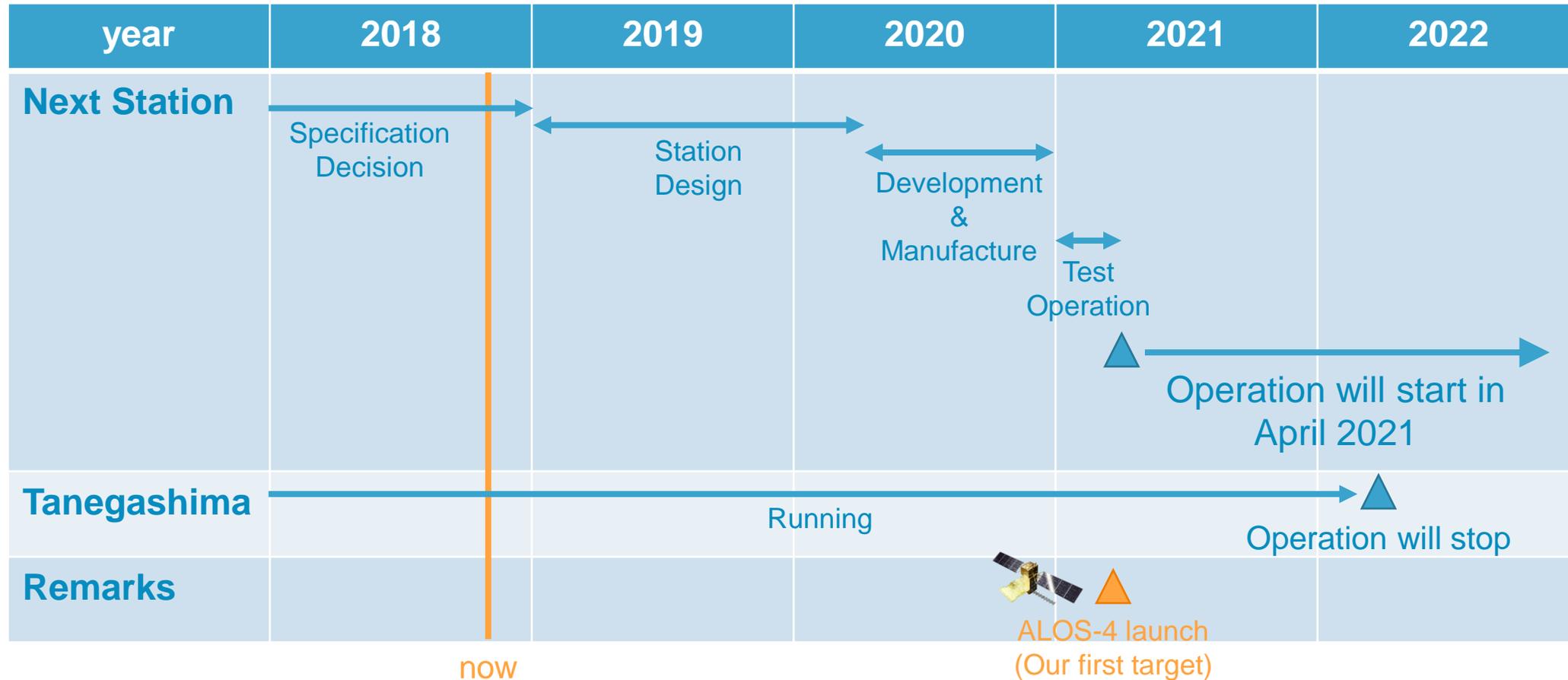
► There are two main reasons

- ✓ We can access there so quickly because our office is in Tsukuba Space Center.
- ✓ Tsukuba has more sunny days than Tanegashima.



Plans of next SLR station - Milestone -

► Milestone of next SLR development



Summary

- ▶ JAXA is planning to build a new SLR station.
- ▶ Several new features will be introduced to next SLR station.
- ▶ We are planning to use both ADS-B and Infrared Camera as a safety system.
- ▶ Next SLR station will be located in Tsukuba Space Center and will start its operation in April 2021.